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GEOHYDROLOGICAL CHARACTERISTICS AND GROUNDWATER DYNAMICS OF NARAVA MICRO WATERSHED, A.P., INDIA

by

Neelapu Lokesh Kumar Reddy, M.Sc.,

Under the guidance of

Prof. K.V.V. Satyanarayana

and

Prof. N.V.B.S.S. Prasad

DEPARTMENT OF GEOPHYSICS

ANDHRA UNIVERSITY, VISAKHAPATNAM - 530 003.

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Introduction:

In recent times there has been an exponential growth in infrastructure development, industry, agriculture and food production, urbanization and recreation resulting in an unprecedented demand for water resources. Unfortunately climatic changes triggered by anthropogenic activities and extreme natural hazards have imposed not only a shift in monsoon cycle, but also frequent failures leading to an uneven distribution of rainfall in time and space. Further many popular and professional programs initiated and implemented by local and central governments unfortunately did not take into cognizance the quantity and quality of both surface and groundwater resources vis-à-vis the local and regional needs. Non-scientific and instantaneous approaches adopted by the government, NGO's, groups and individuals in the direction of sustainability and minimizing surface runoff have lead to an indiscriminate construction of surface water harvesting structures to manipulate the rain water and surface water resources. Though this concept of rain water and surface water harvesting has resulted in increased soil moisture content in the vadose zone and contributed to higher productivity in localized areas, the natural fluvial systems have been substantially hampered with reference to their dynamic characteristics resulting in many uncertainties in water resources quantity and quality. Intensive agriculture practices, unscientific location of harvesting structures, unplanned developmental activities have thus induced reasonably high complexity and uncertainty in the behavior of water quantity and quality regime, be it surface or subsurface. The rapid industrialization and urbanization have made the problem more complex infusing additional uncertainties.

During the last two decades the spurt in the increased water resources utility in agriculture and industrial sectors reflected by the rise in the use of groundwater for irrigation, from a mere 9 % to 47 % during the last two decades from 1989 till now. Thus considering the exponential increase in the use of groundwater in agriculture and other sectors vis-à-vis its availability, the need for an affective management has become highly relevant reducing the importance for the resource development. Numerical models have been

successfully implemented for simulating and predicting groundwater levels for many years. After the calculation of the renewable water resources potential and the water demands, the water balance estimates are made for time and space. However, a number of studies have clearly indicated that an affective management can be accomplished by considering the behavior of water resources regime in small watersheds and integrate them using a synergic approach while scaling up for large areas.

In this context, a small watershed by name Narava micro watershed drained by an ephemeral local river by the same name Narava gedda is taken up to understand and characterize the quantity and quality of both surface and subsurface water regime and the characteristic changes and their dynamic behavior with time and space.

Objectives:

To understand the heterogeneous nature of various components of water resources several techniques have been adopted to capture necessary information. The systematic and scientific approaches have been applied for evaluating the groundwater resources.

The following are the objectives of the present study

- To study different hydrogeomorphic provinces and morphometric characteristics in relation to the groundwater resources.
- To identify the characteristic response of water level, rainfall and associated parameters in time and space domain in different geological terrains.
- To assess the aquifer characteristics and the groundwater potential in the watershed
- Analyze the chemical quality of groundwater and its spatial variation in the watershed and identifying the hydrogeochemical process.
- To develop a conceptual model leading to a numeric model which can be used to simulate the groundwater flow pattern under steady – state conditions
- To suggest effective management strategies for an optimum development and an effective management of groundwater.

Methodology:

In order to achieve the objectives, the followings methods and materials were used:

A base map on a 1:25,000 scale was prepared and after conducting detailed geomorphic surveys. Automatic meteorological stations and rain-gauges were established to record precipitation, temperature etc. Detailed geomorphological and geological features were depicted and land use maps were prepared for khariff and rabi seasons along with estimates of groundwater and surface water utility. Quantitative morphometric analysis along with hydrogeological investigations was carried out.

Detailed geo-electrical surveys were conducted and piezometer wells were constructed at suitable sites (five locations) for monitoring water levels, sub-surface water temperature, etc. Simultaneously some of the existing wells were selected for continuous monitoring of both quality and water levels. The lag times between the occurrence of rainfall events and the corresponding response in groundwater levels were computed. The field data thus collected was used to evaluate ground water parameters. MODFLOW, a modular three dimensional finite difference groundwater flow model developed by the Waterloo Hydrogeologic, Inc. (Mc Donald and Harbaugh, 1988) was adapted in the present studies. All data generated on the following aspects were assembled into a conceptual model in a simplified form.

- Well inventory
- Water level fluctuations
- Hydrochemical characteristics in the conceptualization of groundwater flow models
- Comparison of simulated head water level obtained in the field during model calibration.

Using an integrated approach, strategies for groundwater resources development and management in the region have been suggested.

Structure of the thesis:

Detailed studies on the hydrometeorology, hydrogeomorphology, morphometric analysis, the geological and geohydrological conditions, the water table behavior with respect to rainfall, temperature, pressure, availability of groundwater and surface water resources, groundwater quality and are presented along with the results in seven chapters in this thesis.

The concept of water resources assessment and management in a given micro watershed, the perception and the objectives of the present work, a brief description on the status of work carried out in this area at national and international arena are presented in chapter I.

The geographic location, climate, surface water bodies, landuse, soil type, geomorphology and geology of the area are briefly outlined in chapter II. Hydrometeorological parameters indicate that potential evapotranspiration, in general, tends to increase with increase in temperature and wind speed and decrease in humidity. The prominent geological formations in the area belong to the Archaean system includes mainly khondalite suite of rocks, granite gneisses (leptynites), charnokite, granites, pegmatites and quartz veins. The study area with moderate relief and characteristic geological set up support medium runoff and moderate rain water infiltration. Groundwater exists in the weathered/fractured zone. The drainage density of the basin is 1.419 km/km^2 which indicate the rate of infiltration to be moderate.

The geomorphic features such as structural and residual hills with slopes exceeding 10 m/km resulted in higher runoff and little or no infiltration. The thickness of the weathered zone is ranging between 0 - 3 m with low groundwater recharge. The moderately weathered pediplain, with lineament density >2, weathered zone thickness of more than 30 m, shallow water table classified as moderate to good groundwater prospects. Study area is covered with sandy silts, sandy soils, gravel and laterites. However, along the stream course, sandy clays and silty clays are observed to dominate. The wide variations in land use conditions vis-à-vis the infiltration rates for the same soil regions can be explained with varying contents of moisture and organic matter. It is observed that varied geology, soil cover and land use patterns have resulted in differential recharge conditions. Areas under agriculture are observed to contribute to higher recharge than those with and without scrubs.

Rainfall influence on groundwater table and on different geological formations and geomorphological units, groundwater potential and hydrochemical characteristics have been discussed in chapter III. To evaluate the hydrogeological characteristics, subsurface geophysical properties of Narava micro watershed region and adopt suitable numerical groundwater models to understand the groundwater availability in time and space along with its dynamic behavior. Groundwater dynamics and aquifer replenishment characteristics are discussed in detail, based on the rainfall and water level responses. Finally the general water quality parameters are discussed in the concept of water resources management.

It is observed that the weathered zone with a resistivity varying between 13 - 21 Ω m is significantly contributing to the well yields as well as the recharge characteristics. The variation in the depth to water table values is attributed to heterogeneity in the hydrogeology of the area.

A comparison between the well hydrograph and the associated hyetograph clearly reflects different response and lag times. The lag time, ranging from 5 to 10 days between the occurrence of rainfall events and the corresponding response in groundwater levels, is observed to have a close relationship with local hydrogeological conditions. However, further intensity of rainfall appears to have a direct relationship with raised water levels and does not seem to have a one to one relationship with recharge response time. In general, it is observed that 10 mm of rainfall is a threshold value for triggering the groundwater recharge. The characteristic variation in groundwater temperature vis-à-vis atmospheric temperature and the temperature of recharge water indicates that the change in temperature of groundwater is due to recharge water rather than the lowered atmospheric temperature.

The groundwater quality in the study area qualifies for potability even though the hardness is consistently high. It is found that the groundwater is of Na-HCO_3 type concentrated with Ca^{2+}, Mg^{2+}, Na^{+} and HCO_3^{-} which is supported by alkaline p^H. Spatial and temporal variations of major and minor ions in the waters have been observed, which are considered to be caused by local hydrogeology. The variations in ionic ratios and parameters following a general trend were used to define recharge areas and infer flow directions.

The development of mathematical and numerical groundwater models under steady state conditions, data processing and calibration have been explained in chapter IV. This chapter describes the concepts of groundwater modeling and the implications in characterizing the dynamic behavior of groundwater. The basic principles of groundwater models are discussed in brief along with the development of conceptual models based upon available field measurements. Depending on the available field data and the identified conceptual model, suitable model software is selected and its structure, operation and limitations are briefly outlined.

Application of numerical groundwater models in steady state condition and mathematical representation of boundary conditions for Narava micro watershed was given in the chapter V. In this Chapter, the mathematical model is explained along with the governing equations and mathematical representation of boundary condition. The surface topography is observed to control the groundwater flow conditions in the Narava micro watershed with the general groundwater flow direction being SW-NE. The groundwater velocity vectors indicate the predominant flow towards the north east with maximum groundwater velocity in the watershed to be 0.59 m/day or 5.9×10^{-6} m/s. Groundwater deficit zones have been identified in the western, southern and northern parts of the study area. As predicted from groundwater modeling studies, groundwater stressed areas have been identified and suitable artificial recharge methods have been proposed.

Description of groundwater resource development and management strategies for the region are presented in chapter VI. Suitable locations for construction of rainwater structures are suggested to improve available groundwater resources. By integrating the information on slope, geology, lineament, hydrogeomorphology, lineament density, weathered zone thickness, geoelectrical and hydrogeological cross sections and by overlying these maps, suitable groundwater harvesting sites and structures are proposed.

Finally, the observations and conclusions briefly summarized along with future scope are presented in the chapter VII.

Findings:

Narava micro watershed located in Visakhapatnam district of Andhra Pradesh is predominantly underlain by khondalite suite of rocks and granite gneisses. Narava gedda is an ephemeral stream originating at Gangavaram (250 m amsl) and joins the Mehadrigedda reservoir (10 m amsl). This reservoir is one of the important water storage reservoirs catering to the domestic water needs of Visakhapatnam city. The eastern part of the watershed constitute the Narava hill ranges rises to a maximum height of 380 m amsl, while most of the central, northeast central and southwest central parts exhibit a plain topography.

The geological formations and their structural geometry and the associated geomorphological features control the occurrence and availability of groundwater to a significant extent. \The Narava basin has attained a reasonably good maturity with a fourth order drainage network dominated by dendritic to sub-dendritic patterns. The drainage patterns of Narava are structurally controlled by lineaments.

Correlation and interpretation of the well hydrographs and the corresponding hyetographs in the study area has provided vital information relating to hydrogeological, hydrometeorological and recharge phenomena of the groundwater system. It is observed that the aquifer recharge response can be attributed more to the monsoon rainfall than to the total annual rainfall. Variations in recharge lag times are related to hydrogeological conditions consisting of weathered kaolinised zones and clay zones.

Thick weathered subsurface zones associated with low slopes and high lineament densities in the northern region of central are observed to have good prospects while the areas characterized by thin weathered zones, with steep slopes and low lineament densities have poor prospects for groundwater potential. Based on the existing status of groundwater development and the dynamic behavior of groundwater in the area, the basin can be categorized as ‘safe’ from the perception of groundwater development.

The general ionic concentrations of major, minor and trace elements are observed to have been contributed mostly by the local geological formations constituting feldspar, garnet, pyroxene and sillimanite. The spatial distribution of ionic concentrations projects isolated pockets of anomalous behavior reflecting complex hydrogeological conditions.

Formations with significantly high quantities of clay and weathered material are observed to control this anomalous hydrochemical behavior. Weathering of silicate minerals controls the major ion chemistry of calcium, magnesium, sodium and potassium. In general, the water chemistry of the micro watershed is guided by weathering and ion exchange processes.

Groundwater flow model conceptualized and developed using the lithologic information and aquifer parameters are observed to replicate the trend of observed groundwater contours. The surface topography is observed to significantly control the groundwater flow regime in the watershed**.** The groundwater velocity in the watershed is observed to vary from 0.37 m/day to 0.59 m/d. Abstraction of groundwater for irrigation in the region is found to have a strong impact on the groundwater flow regime resulting in a sharp fall in groundwater head.

Based on the results of the integrated studies encompassing geomorphology, lithology, structure, hydrology including groundwater model studies, effective groundwater management strategies have been proposed.